Journal of
Cognition
and
Neuroethics

How to Defend Embodied Cognition Against the Locked-In Syndrome Challenge

Luis H. Favela
University of Central Florida

Biography

Luis H. Favela is Assistant Professor of Philosophy and Cognitive Sciences at the University of Central Florida. His research is both philosophical and empirical, residing at the intersection of the cognitive sciences, neuroscience, philosophy, and psychology. His primary research aim is to demonstrate the suitability of complexity science and dynamical systems theory to provide the appropriate theories and methods for investigating and understanding mind, where 'mind' includes behavior, cognition, and consciousness.

Publication Details

Journal of Cognition and Neuroethics (ISSN: 2166-5087). February, 2018. Volume 5, Issue 1.

Citation

Favela, Luis H. 2018. "How to Defend Embodied Cognition Against the Locked-In Syndrome Challenge." *Journal of Cognition and Neuroethics* 5 (1): 27–48.

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Luis H. Favela

Abstract

Embodied cognition is the idea that cognition is causally related to and/or constituted by bodily activities. In spite of accumulating reasons to accept embodied cognition, critics seem to have a knockdown argument: appealing to locked-in syndrome (LIS). Patients with LIS are said to be at least minimally conscious to fully awake, except they have no motor control of their body and cannot produce speech. LIS seems to undermine embodied cognition: if cognition is embodied, then LIS patients cannot have intact cognitive capacities because they do not have motor control of their body. The present goal is to provide supporters of embodied cognition with a set of three responses when faced with the challenge from LIS. The first is deflationary and highlights the fact that most cases of LIS are not total and that much evidence of LIS are not actually cases of LIS. The second is skeptical and provides reasons to question the evidence of LIS based on neuroimaging data. The third is that the types of pathologies that cause LIS are likely to alter cognition in radical ways. With these responses at the ready, the supporter of embodied cognition need not surrender at the mere mention of LIS.

Keywords

Cognition, Consciousness, Embodied Cognition, Locked-In Syndrome

Introduction

If there is a generally accepted understanding of cognition, then it is that cognition is a phenomenon that happens in brains and is essentially information processing and representational in nature (Kandel, Schwartz, Jessell, Siegelbaum, and Hudspeth 2013). For the past few decades, this “received view” of cognition has experienced some pushback. The term ‘cognition’ has come to be applied in non-brain-centric ways, for example, “embodied cognition,” or the idea that cognition is causally related to and/or constituted by non-neuronal physiology (Varela, Thompson, and Rosch 1991). One reason given in support of embodiment is that cognition involves bodily action. Be it for purposes of cognitive development (Thelen and Smith 1994) or simulating the mental states of others (Barsalou 2008), proponents of various forms of embodiment argue that cognition relies on bodily states and movements to varying degrees. Such non-brain-centric approaches to cognition are receiving increasing theoretical support in philosophy and empirical evidence in the cognitive, neural, and psychological sciences.

In spite of the evidence and reasons to accept non-brain-centric conceptions of cognition, critics seem to always have a knockdown argument, especially against embodied cognition. The argument centers on appealing to cases of locked-in syndrome (LIS). Patients with LIS are said to be at least minimally conscious to fully awake, except they have no motor control of their body and cannot produce speech. LIS seems to undermine embodied cognition in this way: If cognition is embodied, then LIS patients cannot have intact cognitive capacities because they do not have motor control of their body. The present goal is to provide supporters of embodied cognition with a set of three responses when faced with the ever-looming challenge from LIS. The first response is deflationary and highlights the fact that most cases of LIS are not total and that much evidence of LIS are not actually cases of LIS. The second is skeptical and provides reasons to question the evidence of LIS based on neuroimaging data. The third is that the types of pathologies that cause LIS are likely to alter cognition in radical ways.

In the next section, I present an overview of the received view of cognition and alternative understandings, with a focus on embodied cognition. Next, I present LIS and explain why it is a challenge for proponents of embodied cognition. After, I present responses to the challenge of LIS. With these responses at the ready, the supporter of even the more radical versions of embodied cognition need not surrender at the mere mention of LIS.

The Received View of Cognition and Some Alternatives

It is likely safe to say that most contemporary researchers of cognition in philosophy and the relevant sciences believe that cognition happens in brains (Kandel, Schwartz, Jessell, Siegelbaum, and Hudspeth 2013). Additionally, and at least since the "cognitive revolution" of the 1950s, most of those folks believe that cognition is essentially representational and involves information processing (Miller 2003; Thagard 2005). In regard to behavior, cognition is understood not as a kind of behavior, but as a cause of behavior (Aizawa 2015; Fodor 2008; 2009; Shapiro 2013). Taken together, these four characteristics comprise the contemporary "received view" of cognition: brain-centered, cause of behavior, information processing, and representational. Though popular in textbooks, accounts that present the received view as the only game in town concerning scientific investigations of cognition since the 1950s are false and incomplete. Other approaches to understanding cognition were concurrently in development and practiced alongside the received view.

There is no doubt that research programs investigating cognition based on computational-representational frameworks were heavily influential at least from the 1950s to 1980s (e.g., Good Old Fashioned Artificial Intelligence [GOFAI]), and that investigations of the brain have taken a more central role from the 1990s to today (e.g., connectionism, neural networks, and neuroimaging [Boden 2006]). However, concurrent with such methodologically solipsistic computational-representational approaches (Fodor 1980) were frameworks that shifted focus away from cognition isolated in brains to cognition in *systems* (Favela and Martin 2017). It has been claimed that conceptions of cognition as not isolated in individuals—or, specifically, their brains—has roots in Darwinian biology and Jamesian psychology of the late-1800s to early-1900s (Chemero 2009; Favela and Martin 2017). For current purposes, I focus on ecological psychology as a starting point for thinking about cognition as a systems phenomenon.

There are many available summaries of James Gibson's ecological psychology (e.g., Chemero 2009; Favela and Chemero 2016a; Richardson, Shockley, Fajen, Riley, and Turvey 2008). What matters for now is that Gibsonian ecological psychology, which began in the mid-1900s, provides a theoretically rich and empirically successful alternative to the received view, and one that influenced many of the current non-brain-centric alternatives. Ecological psychologists reject many of the central tenants of the received view. First, cognition, action, and perception are not treated as distinct but as continuous. Accordingly, the cognition/behavior dichotomy is understood as false. Second, cognition is not computational/information processing in nature, representational, or isolated in brains. For the ecological psychologist, cognition is understood as occurring across organism-environment systems. Third, cognition-action-perception are temporal in nature. One favorite example of the ecological psychologist that demonstrates these three features is the outfielder problem.

In short, the outfielder problem is the challenge of explaining how a baseball player can catch a ball that is moving high in the sky. Based on its theoretical commitments, the received view would have to say that the player creates a mental representation of the ball in the sky, computes her location relative to the ball, then—based on stored information cuing features of the environment (e.g., depth based on surface orientation [Marr (1982) 2010])—moves her body towards the ball, updates her mental representations of the ball, recalculates the position of the ball relative to her body, and so on, until her neurally-realized calculations bring her gloved hand to the ball. Alternatively, the ecological psychologist posits a much more parsimonious explanation: the player directly perceives the ball in the sky, and based simply on the changing size of the ball in the sky—that is, the ball appears larger as it gets closer and smaller when further—

moves in its direction and to catch it. As ecological psychologists have argued (Oudejans, Michaels, Bakker, and Dolne 1996), such accounts that take environmental information into consideration in that way provide non-brain-centric, non-computational, and non-representational explanations. Instead of computing indirect mental representations, the ecological explanation offloads information onto the environment (i.e., object size occlusion) and utilizes temporal features (e.g., parallax). The emphasis on the temporal dimension of cognition-action-perception facilitated a fruitful combining of ecological psychology with dynamical systems theory.

Dynamical systems theory (DST) originated with Newton's invention of differential equations to help explain planetary motion. The emphasis placed on the temporal properties of phenomena lead some in the cognitive sciences to wonder whether cognition is dynamic in nature or, at the very least, whether the methods of DST could illuminate understanding of cognition (e.g., van Gelder 1998). The typical DST treatment of a phenomenon includes capturing the relevant variables within differential equations and plotting the phenomenon in a phase space, which represents all possible states of the system over time. When thinking about DST approaches, it helps to keep in mind their emphasis on principles of behavior. Instead of decomposing a phenomenon to see what it is made of and what is the primary/first cause of its behavior, DST approaches focus on how the states of the system evolve over time according to a rule (Riley and Holden 2012). These rules (or principles) are often written with differential equations, which include order parameters (macroscopic states of system), and control parameters (variables guiding system dynamics [Haken (1988) 2006]). Two features of DST explanations are especially important for current purposes. First, from an explanatory perspective, DST models do not make a priori discriminations about where in the world things represented by variables should be located. Second, and following from the first, since DST accounts do not dictate where boundaries ought to be, what counts as a "system" can sometimes be counterintuitive (Beer 1995; Chemero 2009).

Consider, for example, the following coupled differential equations:

(1) $\dot{x} = x + 2y$

(2) $\dot{y} = 3x + 2y$

These two equations are "coupled" in the sense that any changes to one will affect the other. Thus, if the value of x in (1) is increased and thereby resulting in an increase in $\dot{x}$, then so too will there be an increase in x in (2), which will thereby result in an increase in $\dot{y}$. Suppose that (1) and (2) are two coupled equations that model and explain how one person's arms moves while clapping. It would be easy to say the equations depict a single system—(1) represents the left arm and (2) the right arm. Now, suppose that (1) and (2) are two coupled equations that model and explain how one person's arm (x) moves while tossing a ball (y) in the air and catching it. That might be more difficult to accept as a "single system" for various reasons, for example, because the ball is inorganic, not attached to the person, etc. Yet, as the model indicates, any changes to one variable (y) is determined by changes in the other (x). I do not know if dynamicists would typically accept that the ball-and-arm count as one system. However, the example is instructive in its ability to flesh out what DST has pushed investigators of cognition to consider, especially the location of factors relevant and constitutive of cognition.

Given the explanatory virtues DST approaches facilitate (e.g., controlled manipulations, predictions, etc.), it is not so easy to dismiss their sometimes-counterintuitive consequences. For example, given the nature of the relationships among variables depicted by DST models and plots, it may be necessary to rethink whether a phenomenon is merely a set of distinct but coupled components, or if those components are so tightly related that they *constitute* the phenomenon. It is this ability to model systems with sometimes-counterintuitive variables that mesh so well with ecological psychology (Favela and Chemero 2016b; Kugler, Kelso, and Turvey 1980). As mentioned above, ecological psychologists explain events such as fly-ball catching with an eye towards the system, and not isolated organisms. As a result, the baseball player, field, and ball play roles in complete solutions to the outfielder problem. With the tools of DST, the ecological psychologist can explain how such variables can (even counterintuitively) constitute one system, which can be evidenced by such empirical findings as alterations to one part of the system (e.g., ball location) affecting other parts of the system (e.g., player location). The theoretical and methodological successes of ecological psychology and DST (taken together and alone) prompted a range of reasons to think that cognition is not just in the head.

Along with the received view, fruitful alternative frameworks were conducting research guided by such theories as those found in ecological psychology and methods such as DST. One consequence of such frameworks has been the possibility that cognition is not centered in the brain, nor computational or representational. A number of non-brain-centric approaches began to surface in the 1980s and 1990s. These included treatments of cognition as distributed, embodied, enactive, extended, and situated. Such views have not merely been argumentative or theoretical considerations, but have become increasingly influential in philosophy and the cognitive, neural, and psychological sciences (for reviews see Favela 2014; Favela and Chemero 2016b; Favela and Martin

2017). Here I focus on embodied cognition. Embodied cognition is a non-brain-centric position concerning what causes and constitutes cognition (Anderson 2003; Richardson, Shockley, Fajen, Riley, and Turvey 2008; Rowlands 2010; Varela, Thompson, and Rosch 1991; Wilson 2002). It is important to note that "embodied cognition" is not equivalent to "embodied mind" (Favela and Chemero 2016b). Embodied mind is a metaphysical thesis about the nature of mental states. For example, the idea that mental states occur not just in the brain but in the body as well can be viewed as functionalist in nature, namely, that mental states are defined by particular realization relationships that extend into the body (cf. Wilson 1994). Embodied cognition, on the other hand, does not necessarily make claims about the metaphysics of mind, and could be consistent with various metaphysics such as eliminativism, functionalism, or identity theory.

Although there is no single "embodied cognition," the general thesis is that the body's sensory and motor processes constrain and enable cognition (Foglia and Wilson 2013; Thompson 2007). There is a wide range of consequences that thesis has for how we consider cognition. Conservative versions of embodied cognition treat cognition as computational and representational in nature (Barsalou 2008; 2010; Wilson 1994). These conservative versions treat cognition as essentially representational in nature, but the representations are not necessarily realized neuronally or of a single kind, for example, the body can temporally represent states such as another's pain (Barsalou 2008). Others claim that cognition can extend to tools and the environment (Clark and Chalmers 1998; Fiore and Wiltshire 2016; Hutchins 1995). Such extended and distributed forms of cognition can be conservative and remain consistent with cognition as computational-representational. For example, addresses in one's smartphone can serve as external representations that can be accessed via information-processing means (i.e., functionalism [Clark and Chalmers 1998]). Finally, there are radical versions that reject the idea that cognition involves any information-processing or representations. Instead, cognition is non-computational and non-representational, and is fundamentally constituted by the dynamics of brain-body-environment systems (Chemero 2009; Kelso 1997; 2009; Port and van Gelder 1995; Thelen and Smith 1994). Whether one adheres to radical conceptions of embodiment or not, embodied cognition has become an influential branch of cognitive science (Calvo and Gomila 2008; Chemero 2009; Dale 2008; Favela and Martin 2017; Glenberg 2010; Riley, Shockley, and Van Orden 2012). What is more, even researchers in the neural sciences are acknowledging both the causal and constitutive roles the body plays regarding cognition (Edelman 2006; Favela 2014; Sporns 2010; Tognoli and Kelso 2014).

Until now, I have attempted to motivate the case that various substantial research programs have investigated cognition as long as the received view has. Some of these programs share features of the received view—for example, that cognition involves some form of information processing—but some are radically different. For example, ecological psychology rejects the received view's treatment of cognition, action, and perception as distinct, and DST facilitates understanding cognition as fundamentally temporal in nature. Taken together, ecological psychology and DST have served as precursors for non-brain-centric conceptions of cognition. Various theories and methods now investigate cognition as, for example, distributed, extended, and situated. One of the more robust forms of non-brain-centric cognition is embodied cognition, which continues to gain increasing theoretical and empirical support across philosophy and the mind sciences. Still, there are many critics of embodied cognition, especially of the radical sort that rejects understanding cognition as computational or representational. One knockdown argument against embodied cognition—especially radical versions—at the critic's disposal is the appeal to locked-in syndrome, which I turn to in the next section.

The Locked-In Syndrome Challenge

In general, a patient has locked-in syndrome (LIS) when she is fully awake but cannot move her body or verbally communicate. The LIS challenge to embodied cognition can be understood as primarily motivated by the following question: if cognition is embodied, then how can patients with LIS have intact cognitive capacities despite having no motor control of their body? The argument is as follows: First, embodied cognition claims that cognition is causally related to and/or constituted by the body's sensorimotor activity. Second, LIS patients have intact cognition despite being unable to move their body. Third, LIS patients have intact cognition without their cognition being embodied. Therefore, cognition is not embodied. Thus, embodied cognition is an incorrect theory about the nature of cognition. In the remainder of this section, I will explain in more detail what LIS is and why it is more of a challenge for some forms of embodied cognition than others.

Patients with LIS are at least minimally conscious to fully awake, except they have no motor control of their body and cannot produce speech (Owen 2013). LIS typically results from strokes (86.4%; [León-Carrión, Van Eeckhout, Dominguez-Morales, and Perez-Santamaria 2002]), and is caused by:

> a primary vascular or traumatic injury to the brainstem, normally corresponding to a ventral pons lesion due to an obstruction of the basilar artery, and characterized by upper motor neuron quadriplegia,

> paralysis of lower cranial nerves, bilateral paresis of horizontal gaze and anarthria, and with preserved consciousness. (León-Carrión, Van Eeckhout, Dominguez-Morales, and Perez-Santamaria 2002, 571)

LIS is not considered a disorder of cognition (Schnakers, Majerus, Goldman, Boly, Van Eeckhout, Gay, Pellas, et al. 2008), that is, LIS patients do not exhibit cognitive deficits such as impaired intelligence or memory. Additionally, LIS is not considered a disorder of consciousness (Owen 2013), that is, LIS patients are able to be awake and to distinguish sleeping from waking states. Though patients with LIS cannot produce speech, many can produce sound (78%; León-Carrión, Van Eeckhout, Dominguez-Morales, and Perez-Santamaria 2002) and the majority have vertical eye movements (Schnakers, Laureys, and Boly 2013), which means they have nonverbal communicative abilities. However, due to complete immobility that includes eye movement, some patients are diagnosed with *total LIS* (TLIS; Bauer, Gerstenbrand, and Rumpl [1979]).

TLIS is extremely difficult to diagnose. To be LIS is to not exhibit deficits in cognition or consciousness. This can be relatively straightforward to diagnose, as most LIS patients can communicate nonverbally, either by sound or eye movements. Thus, rudimentary forms of communication can be utilized to assess states of consciousness and cognitive capacities, for example, by moving eyes in a particular direction a certain number of times to indicate a letter in the alphabet. However, TLIS cannot utilize even those rudimentary means. Thus, it can be very challenging to diagnose a patient with TLIS as opposed to persistent vegetative state, which is a disorder of consciousness (The Multi-Society Task Force on PVS 1994). One approach to diagnosing TLIS in non-communicative patients is via functional magnetic resonance imaging (fMRI) to assess neuronal responses while the patient listens to spoken sentences (Owen, Coleman, Boly, Davis, Laureys, and Pickard 2006). In such experiments, speech-specific activation is assessed in areas of the brain that activate when non-TLIS subjects hear similar sentences. However, as Owens and colleagues (2006) point out, just hearing sounds and having accompanied neural activation does not mean the subject has conscious awareness of the sentences, that is, the subject's brain could merely have nonconscious sound or semantic processing. Accordingly, more sophisticated tests are needed, such as asking a potential TLIS patient to conduct mental imagery tasks in order to modulate their own neural activity in a manner that may not be as likely to result from automatic and/or nonconscious processing (Owen, Coleman, Boly, Davis, Laureys, and Pickard 2006). If such tasks are successful, namely, if TLIS patients can communicate mental states—for example, fMRI detection of activity in neural areas following responses to task prompts such as "imagine playing tennis"—then it could be a major blow to embodied cognition.

Such findings would undermine embodied cognition because it would suggest that cognition is not sufficiently caused or constituted by the body, let alone necessarily so. Conservative forms of embodied cognition may be more readily poised to respond to the TLIS challenge. Perhaps the body was necessary in the development of cognitive capacities (cf. Thelen and Smith 1994) such as simulating states of others (cf. Barsalou 2008), but, once that ability is acquired, then the capacity can occur offline, that is, without the body. On the other hand, TLIS appears to be particularly devastating to radical embodied cognition, for it is committed to the idea that cognition is necessarily bodily: no sensorimotor capacities means no cognition. It appears that the thesis of radical embodiment—namely, that cognition is necessarily sensorimotor in nature—is disproven by TLIS patients who can conduct cognitive tasks offline by thinking about it in their head and without any body movement. Is it time then for proponents of radical embodied cognition to throw in the towel? No, proponents of radical embodied cognition are not doomed by the LIS challenge. In the next section, I provide three kinds of responses that proponents can offer when faced by the LIS challenge.

Saving Embodied Cognition from the Locked-In Syndrome Challenge

In the previous section, I presented the locked-in syndrome (LIS) challenge to embodied cognition: if LIS patients have intact cognitive capacities, then embodied cognition cannot be a correct theory of cognition. The apparent evidence of intact cognitive capacities in total LIS (TLIS) patients appears to make matters even worse for proponents of radical embodied cognition. In this section, I provide supporters of embodied cognition with a set of three responses to the LIS challenge: the first response is deflationary; the second is skeptical; and, the third raises concerns about the equivalence of cognitive states had by patients with TLIS compared to those without.

The first response to the LIS challenge is deflationary; specifically, most cases of LIS are not total and key cases in support of TLIS are actually not cases of LIS. The majority of patients with LIS have some degree of body movement (e.g., eye movement [Schnakers, Laureys, and Boly 2013]) and can communicate. In fact, many cases appealed to in the LIS challenge are not LIS at all. Take the "imagine playing tennis" example from Owen and colleagues' research (2006). As mentioned above, in order to attempt to control for detecting only nonconscious processing, Owen and colleagues asked potential TLIS patients to intentionally participate in tasks involving mental imagery. For example, if a patient was known to enjoy playing tennis, then she was asked in experimentally controlled ways to imagine playing tennis, and if via fMRI scans neural activation was detected in motor areas of the brain, then it was presumed to be evidence that the patient was consciously aware enough to conduct that cognitive task. However, that particular set of experiments by Owen and colleagues was not intended to be a test for TLIS. It was a test, not of cognitive states, but of consciousness in patients in *persistent vegetative states* (PVS). Unlike T/LIS, which is categorized not as a disorder of cognition or consciousness, PVS is a disorder of consciousness: "The term describes a unique disorder in which patients who emerge from coma appear to be awake but show no signs of awareness" (Owen, Coleman, Boly, Davis, Laureys, and Pickard 2006, 1402). Moreover, PVS is a "clinical condition of complete [conscious] unawareness of the self and the environment, accompanied by sleep-wake cycles" (The Multi-Society Task Force on PVS 1994, 1499). Other disorders of consciousness that are not cases of T/LIS include comas, minimally conscious states, and brain death (Schnakers, Laureys, and Boly 2013). Thus, proponents of embodied cognition ought not to be swayed by many cases presented as evidence that LIS undermines embodiment because many of those cases are not actually LIS.

Another reason to deflate the significance of the LIS challenge is that such cases do not actually undermine the embodiment thesis in two key ways. Remember, embodied cognition is centered on the claim that cognition is causally related to and/or constituted by sensorimotor activity of the body. Moreover, such sensorimotor activity is necessarily temporal—see the above discussion of ecological psychology and dynamical systems theory. In many ways, patients with LIS still meet that criteria: "97.6% were temporally oriented" and "[n]early 100% of the patients reported being sensitive to touch to any part of their bodies" (León-Carrión, Van Eeckhout, Dominguez-Morales, and Perez-Santamaria 2002, 571). In short, nearly every LIS patient experiences their body in space and time, which is fundamental to the embodiment thesis. Thus, proponents of embodied cognition ought not to be so quick to equate a lack of motor control with an absence of bodily experience of the kind necessary to underlie cognition.

The second response to the LIS challenge is skeptical; specifically, there are good reasons to question how compelling the supposed evidence of TLIS is. Much of the evidence of TLIS relies on neuroimaging (e.g., Owen, Coleman, Boly, Davis, Laureys, and Pickard 2006; Pistoia and Sara 2012; Schnakers, Laureys, and Boly 2013). There are a number of deep methodological issues concerning neuroimaging that go far beyond the scope of the current work (e.g., Shulman 2013; Uttal 2001; 2011). In terms of defending embodied cognition against the LIS challenge, I focus on one major assumption involved in interpreting neuroimaging data that may undermine such evidence as counting against the notion that cognition is embodied. That assumption is the presumed modular organization of the brain.

Neuroimaging experiments typically rely on the a priori assumption that mental states are modular and can be spatially and causally localized in the brain (Huettel and Song 2009). This claim assumes that if activity—such as blood flow in the case of fMRI—increases in an area of the brain during an experimental task, then that area of the brain is associated with a particular capacity. For example, if, during linguistic-related tasks, brain location X (e.g., Broca's area) exhibits increased blood flow, then that part of the brain is implicated with a linguistic capacity, such as language production. This assumption underlies a central method of the neural sciences: dissociations. Dissociations occur as follows: if location X is lesioned (e.g., a tumor in Broca's area is removed), and if a linguistic capacity is impaired (e.g., language production), then that is taken as even more evidence that location X is the primary location of those linguistic capacities. There are many practical reasons to justify the modularity assumption and method of dissociation (and double dissociations) in experimental practice. Attempting to decompose and localize parts of a system is often a first step in the scientific investigation of minimally understood and, often, highly complicated systems (Bechtel and Richardson [1993] 2010). The brain is one such minimally understood and highly complicated system. However, there are significant limits to the ability of such data from neuroimaging experiments that assume modularity to serve as evidence against embodied cognition.

The first limit I draw attention to concerns the circularity of such claims. As Van Orden and colleagues state:

> Modularity assumes morphological reductionism: Component effects reduce to underlying modules of mind and brain, and modules reduce to elementary causal microcomponents or *single causes*… Component effects are the structures of behavior, which are reduced to the structures of mind and brain. The assumption of single causes is the core assumption of modular research programs. (2001, 113; italics in original)

In other words, modularity assumes that mental phenomena have single causes, and when a particular phenomenon is made up of the combination of more basic capacities, then those more basic capacities have their own single causes. However, as Van Orden and colleagues forcefully argue, assuming modularity actually undermines the ability of dissociative methods to converge on fixed sets of exclusionary criteria to define pure cases of dissociations (2001, 148). Such an inability of appealing to dissociations to locate modules ends up perpetually fractioning mental capacities into more and more modules and evermore finer grained locations (see Van Orden, Pennington, and Stone 2001 for detailed discussion). This is circular because built into the modularity assumption are theories about the nature of the mental states being dissociated. To claim that lesioning Broca's area dissociates language production capacities is to already have a theory about what language capacities are. Such theoretical commitments are not in themselves a weakness of neural sciences. Without definitions of concepts and theoretical commitments, an investigator would have no way of controlling an experiment or interpreting results. What makes modularity an unjustifiably circular assumption is that evidence of dissociations are searched for until they support a theory that is consistent with modularity. Consider the following example: Pierre Paul Broca had a patient named Louis Victor Leborgne who could vocally only produce the sound "tan" (Domanski 2013; Van Oden and Kloos 2003). If one is committed to modularity being the correct general theory about the structure of mental states in the brain, and if dissociations provide evidence for modularity, then Leborgne's ability to say "tan" while not being able to produce any other sound would be evidence for a "*tan* module" that is distinct from the other language module(s). If cases like Leborgne's were indeed evidence that dissociations bolster the case for mental modules, then modularity would be an absurd theory of mental states in light of an unjustified circularity of reasoning.

In addition to the problem of circular reasoning and its unintended absurd consequences (i.e., the "*tan* module"), the second limit of assuming modularity concerns the nonexistence of what I refer to as the "Cartesian module." Assuming mental modules can be localized in typically developed brains, there is a further issue concerning how brain lesions affect mental states. Perhaps typically developed brains share very similar modular organization at some compelling scale. If true, then the history of neuropsychology/science could very well be justified in appealing to dissociations to prove the existence of language modules, visual modules, reasoning modules, etc. However, the fact is that, after injury, the brain can reorganize so that mental capacities occur in sometimes very different gross anatomical areas of the brain—not to mention microscale areas. To a certain degree, even the proponent of modularity would agree that the brain reorganizes—after all, plasticity is necessary for learning. Nevertheless, what I point to now is more radical forms of neuronal degeneracy, which is the ability of structurally different elements to produce the same function or output (Edelman and Gally 2001). It becomes much more challenging to defend modularity when faced with the evidence of neuronal degeneracy, for example, numerical processing in varying areas of the brains of different subjects (Krause, Lindemann, Toni, and Bekkering 2014), reorganized sensorimotor cortex in people born without particular limbs (Hahamy, Macdonald, Heiligenberg, Kieliba, Emir, Malach, Johansen-Berg, et al. 2017), and significant motor control without a cerebellum (Lemon and Edgley 2010). In addition to serving as considerations in opposition to the modularity theses, the previously stated examples of degeneracy also serve as evidence of the highly interconnected organization of the brain and, possibly, mental states.

What matters for current purposes is that the high degree of the brain's interconnectedness makes it very challenging to draw clear conclusions about the nature of the relationship among brain regions, cognitive ability, and conscious states (Bardin, Fins, Katz, Hersh, Heier, Tabelow, Dyke, et al. 2011). Consequently, and taken together with the first limit of modularity discussed above, it becomes unjustifiable to assume that whatever neuronal pathologies result in LIS have no effect on conscious thinking. For example, if modularity were true of neuronal capacities, then lesioning areas of the brain associated with motor control would have no effect on mental imagery related to bodily action. If true, then LIS patients would be in a "*Cartesian-like state*, in which thinking and acting are mutually dissociated" (Pistoia and Sara 2012, 2329; italics in original). In other words, for modularity to serve as a reason to disagree with the embodiment thesis, then it would be necessary for consciousness to reside in a "Cartesian module" where consciousness occurs in isolation. A Cartesian module would in this way be encapsulated from other brain and bodily properties, even those related to particular phenomenal states such as "visual processing modules" isolated from visual phenomenology that occurs in the Cartesian module. In summary, the second response to the LIS challenge is a set of reasons to be skeptical of the primary evidence of TLIS. That primary evidence is neuroimaging experiments that assume modularity, where modularity is circularly justified via dissociations. Additionally, the highly interconnected and degenerate nature of the brain's organization calls into question the ability to dissociate a "Cartesian module" of consciousness from modules related to particular kinds of phenomenal states.

Following from the second response, the third response to the LIS challenge raises concerns about the equivalence of cognitive states had by patients with TLIS compared to those who are not locked-in. To see why, we must first reject Cartesian consequences of modularity and dissociation-based evidence, specifically, that cognition and consciousness can remain unaltered even when dissociated from sensorimotor capacities. If cognition and consciousness cannot be dissociated from sensorimotor capacities without being altered themselves, then there should be significantly noticeable differences between when they are and are not. If so, then we ought to consider the likelihood that patients with T/LIS have altered cognitive capacities and conscious experiences.

Remember, LIS is not categorized as a disorder of cognition or consciousness: a patient with LIS does not have any cognitive impairment and their conscious states are the same as when they were not locked-in. Therefore, the embodiment thesis is false. But then again, should we be so quick to accept that cognition and consciousness are unaltered in LIS? One set of reasons to not accept that cognition and consciousness are unaltered is a consequence of the second response to the LIS challenge given above. In short, the brain is so highly interconnected that it is unlikely that consciousness could exist in a Cartesian module that would be unaffected by alterations to other areas of the brain that it is connected to. Thus, if somebody has a stroke that results in damage to a part of their brain, then other areas would be affected as well due to the highly interconnected nature of the brain. If true, then a consequence of this claim is that damaging areas of the brain related to motor control would affect motor-control-related conscious experiences. To see why this is likely, consider cases of temporary motor-control paralysis.

Curare (*d*-Tubocurarine) is used by hunters to induce paralysis and, when combined with other anesthetics, to block pain during surgery. The paralyzed eye hallucination is an intriguing result that sometimes occurs due to curare use (Chemero and Cordeiro 2000; Favela and Chemero 2016a; Matin, Picoult, Stevens, Edwards, Jr., Young, and MacArthur 1982). Curare is used to induce temporary paralysis of voluntary movements in surgical patients. Upon waking after surgery, some patients are still incapable of voluntary motor-control that includes eye movement. Some of those patients report that when they tried to look around the room, their visual phenomenological experience was of the entire room moving in the direction they intended their eyes to move. For example, a patient's attempt to look left is unsuccessful because the muscles surrounding her eyes are paralyzed, though she has a visual experience of the whole visual field jumping to the left for a moment. One explanation of this phenomenological experience is that it is the result of perception being inextricably tied to embodied action. Though for a moment the patient has a visual experience of parts of her body, medical equipment, paintings on the wall, etc. jumping in the direction she intended to look, because there is no proprioceptive feedback, the visual experience is short-lived. Over time the patient's initial hallucinatory phenomenological experiences discontinue due to the lack of actual movement in the environment.

Accounting for the paralyzed eye hallucination scenario in this way serves as a response to the LIS challenge to embodied cognition. The primary reason is that it provides a vivid example to support the claim that if patients with TLIS have cognition and consciousness, then it is likely that those capacities are altered in radical ways. By "altered in radical ways," I do not mean those states are deficient per se. I mean that the kind of cognition and consciousness had in locked-in states are unlike the kinds had when not locked-in. Thus, TLIS should not be considered a challenge to embodied cognition. The reason is that the embodiment thesis involves a set of claims (e.g., perception-action linked, cognition happens over time, etc.) about what is causally and constitutively relevant to cognition in particular systems. In cognitive systems like humans that are not locked-in, cognition and consciousness will be a particular way. This is the human perceptual life-world, or *umwelt* (von Uexküll [1934] 2010). As the paralyzed eye hallucination demonstrates, the umwelt of a human with TLIS will be radically different: the absence of motor-control results in unusual phenomenological experiences. Humans who do not have TLIS have kinds of visual experiences that do not include abrupt shifts of their entire field of vision like those experiences had when under the influence of curare. Consequently, due to the highly integrated nature of the brain, the injuries that caused TLIS have the consequence of altering the nature of locked-in patients' cognition and consciousness. This conclusion does not undermine the embodiment thesis, it provides more support for it.

Conclusion

The "received view" is that cognition is a brain-centered cause of behavior that involves information processing and is representational. Following work in ecological psychology and dynamical systems theory, the embodiment thesis claims that the body's sensory and motor processes constrain and enable cognition. Radical versions of embodied cognition claim that cognition does not involve any information processing nor representations, and is necessarily a systems-level phenomenon that involves brain, body, and environment interactions. In spite of evidence in support of the embodiment thesis, one objection seems to serve as a knockdown argument, especially against radical embodied cognition: locked-in syndrome (LIS). Patients have LIS when they are fully awake but have no voluntary motor-control and cannot verbally communicate, though they can move their eyes. Total LIS (TLIS) is when a patient cannot move their eyes either, thereby eliminating even rudimentary forms of communication made possible via eye movements. In short, the LIS challenge claims that cognition cannot be embodied (i.e., grounded in sensorimotor processes) because TLIS patients are presumed to have unimpaired cognition and consciousness despite having no motor control of their body.

I have attempted to provide three types of responses to the LIS challenge. Moreover, these responses are intended to save even radical embodied cognition from the challenge of TLIS. The first response is deflationary: most cases of LIS are not total and key cases in support of TLIS are actually not cases of LIS. The second response is skeptical: there are good reasons to question the ability of the current set of commitments of neuroimaging experiments to allow such data to serve as evidence of TLIS. The third response calls into question the equivalence of mental states had by patients with T/LIS and those that do not. This set of responses give proponents of embodied cognition—including the more radical varieties—reasons to not immediately raise a white flag in surrender at the mere mention of locked-in syndrome.

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